Zen Belt - Deformable Interfaces for Guided Breathing Exercises

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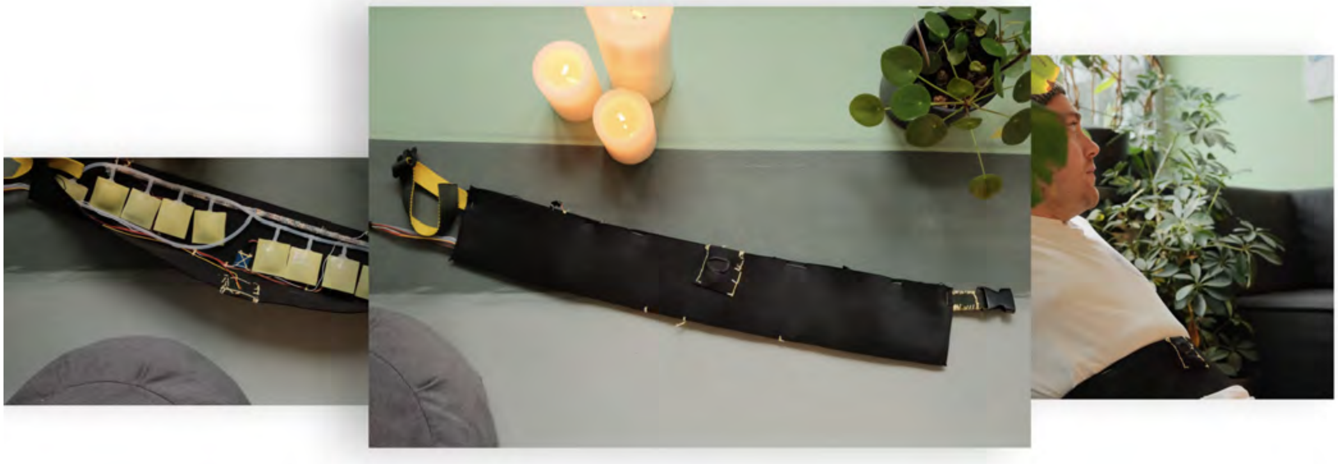

Figure 1: Zen Belt - Hardware Prototype for Guided Breathing Exercises

Abstract

Breathing exercises have shown significant mental well-being and stress reduction benefits. Yet current tech often lacks intuitive experiences that adapt to users' needs. Zen Belt provides multimodal guidance for breathing exercises through a combination of pneumatic actuation and stretch sensing. Our prototype employs custom-made silicone air cushions that inflate and deflate against the user's abdomen. These are synchronized with audio and slight vibrations to guide box breathing. Zen Belt differs from prescriptive approaches that force rigid breathing patterns; it adapts based on real-time feedback. This is possible through a self-knitted stretch sensor that monitors respiratory movements. Iterative prototyping and preliminary user testing illustrate how interfaces can create intuitive experiences for guided breathing. This contributes to embodied interactions research by showing how tactile feedback can enhance immersion in mindfulness practices.

CCS Concepts

• **Hardware → Sensors and actuators**; *Electro-mechanical devices.*

Keywords

Guided Breathing, Sketching With Hardware, Deformable Interfaces, Inflatables

*Both authors contributed equally to this research.

1 Introduction

Guided breathing exercises offer numerous benefits, including improved attention, self-regulation, and mental health. However, current solutions lack a fully immersive and adaptive experience. This report presents the "Sketching with Hardware" prototype, designed to address these limitations by integrating multimodal feedback and adaptive technologies.

2 Related Work

2.1 Benefits of Breathing Exercises

It is widely acknowledged that breathing exercises have a positive effect on mental and physical health. Research has demonstrated the efficacy of practices such as meditation and diaphragmatic breathing in reducing anxiety, improving mental well-being, and improving cognitive abilities, including sustained attention and self-regulation [6]. *Respiratory Sinus Arrhythmia Biofeedback-based Breathing Training*(RSA-BT) has been used as a complementary treatment for conditions such as asthma and as an effective exercise to reduce anxiety [8].

2.2 Technology-Supported Breathing Interventions

Technology has the capacity to improve breathing exercises by providing feedback mechanisms that help users maintain focus and adhere to the appropriate techniques. Systems such as *BreathCoach* illustrate how technology can monitor key biosignals and provide real-time guidance [8]. Currently, Pisa et al. have also demonstrated the development of a system that detects loss of concentration through changes in breathing patterns and provides auditory feedback to help users regain focus [6]. However, many existing applications rely on guided meditation, in which users must follow instructions at a predetermined pace, which can be challenging for novices who have to follow instructions simultaneously and self-evaluate their performance [6].

2.3 Deformable and Tactile Interactions

Recent research has explored how deformable and shape-changing interfaces can create more intuitive and engaging breathing guidance. Karpashevich et al. investigated a garment that changes shape, the Soma Corset, which integrates sensing and actuation around the torso, creating tight interaction loops that provide tactile feedback corresponding to breathing patterns [5]. In a similar approach, Iskanderani et al. developed "Breezy the Calm Monster", a soft toy with sensing capabilities designed to teach children deep breathing techniques through physical and interactive features [4].

2.4 Adaptive vs. Prescriptive Approaches

The majority of contemporary solutions adopt prescriptive approaches, wherein users are required to conform to breathing patterns. Yamaoka et al. found that guided-breath interventions could sometimes lead to distraction rather than concentration [9]. Tsaknaki et al. explored sensing non-habitual breathing patterns, emphasizing the importance of creating a "tactile impact of the sensor data on the body" to develop symbiotic experiences between biosensors and bodies [7]. This underscores the necessity for reactive systems that adapt to users' natural breathing patterns, as opposed to imposing rigid instructions.

3 Our Design Concept

In order to tackle these challenges, our concept is based on three hypotheses:
First, tactile feedback is best located where most of the breathing is happening, similar to the shape-changing sensor-actuator pillows approach by Karpashevich et al. [5], positioned close to the diaphragm area.
Second, the closer the tactile feedback to the actual breathing action, the less mental load is needed to map the feedback to the action, as demonstrated by Tsaknaki et al. who found that pressure applied against the body creates "a tactile somatic experience of non-habitual breathing that could be felt externally" [7].
Third, multi-modality allows a user to immerse better into the exercise, as seen in Iskanderani's "Breezy the Calm Monster" [4] which combines physical soft toy elements with digital interactions and storytelling to create a more engaging breathing experience.

3.1 Prototype - Sketch

The overarching objective was to construct a malleable belt (cf. Figure 2) that would serve two primary functions: firstly, to quantify respiration during physical exertion; and secondly, to assess the impact of exercise on stress levels, utilizing heart rate as a surrogate indicator. Concurrently, the device is designed to provide intuitive feedback to the user, guiding them through the breathing exercise. The chosen exercise, termed 'box breathing', involves equal durations of inhalation, breath retention, and exhalation [1].

Figure 2: First sketch - *ZenBelt*

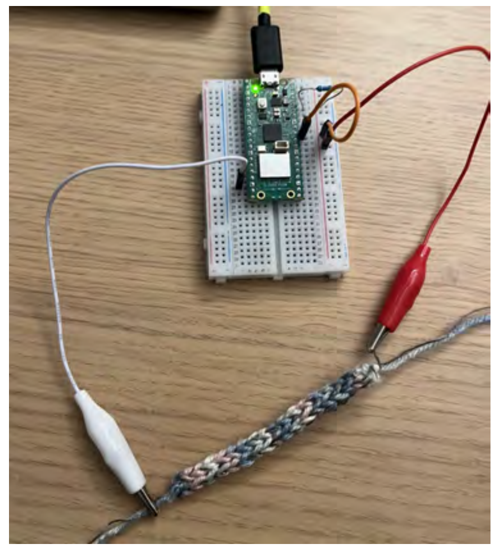

Figure 3: Knitted stretch sensor prototype (small variant)

4 Methodology & Components

In order to build the mentioned belt, several sensors and actors were necessary.

4.1 Stretch Sensor & Belt

We created a self-knitted stretch sensor (see [2]) and integrated it into a stretchable-fabric belt. This self-knitted sensor outperformed traditional stretchable rubber (i.e. *Adafruit)* and bending sensors in measuring respiration patterns.
To facilitate ease of use and ensure compatibility with multiple users, the belt was equipped with a buckle and a non-stretchy strap. This configuration enabled users to adjust the strap's length, and we meticulously recorded all deformations using a stretch sensor.

4.2 Pneumatic System & Silicone

A 3D-printed mold was utilized to fabricate custom silicone pads, as documented on *Instructables* [3]. The pneumatic system, which

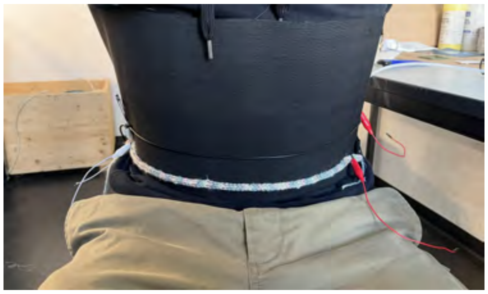

Figure 4: Stretch sensor belt tests

Figure 5: First tests of the final version of the silicone pads

is controlled via an H-Bridge, allows for precise manipulation of air pumps for inflation, holding, and deflation, using pulse-width modulation. The H-Bridge is directly connected to a 5V power bank, which is controlled by the micro controller. The two air pumps are necessary to perform inflation and deflation. The air cushions are connected in parallel to an air valve that controls the airflow to either of the air pumps.

4.3 Multi-Modality & Feedback

In addition to the stretch sensor and air pumps, the prototype includes an audio player (*DFPlayerMini* with an *Adafruit* speaker /w an amplifier) and vibration actors for additional feedback modalities. The audio voice was generated using *ElevenLabs*.

4.4 User Flow & Testing

The prototype was tested with several users to refine the timing of instructions and feedback for the "box breathing" technique, ensuring a calming and effective experience.

The preliminary trials indicated that the air pads were indeed intuitive for the user, yet the presence of a guiding voice was still required. It was evident that first-time-users required guidance to understand that deflation of the pads signifies inhalation and vice versa. Additionally, a gentle vibration to indicate the initiation of a new phase (inhale, exhale, or hold) was found to be supportive.

Figure 6: Production of the final version of the silicone pads

Figure 7: User tests

4.5 Heartrate Sensor

In a subsidiary effort, an attempt was made to monitor a user's heart rate. However, the process of processing the raw signal on a micro controller was found to be rather challenging. Consequently, we opted to exclude this feature from the final prototype, as its integration was not entirely fitting with the topic of deformable interfaces.

Thus, we decided to implement it as an add-on to our main product. Fabric cutouts were utilized to create a wristband connected to a micro controller, see Figure 8. This wristband was then connected via Bluetooth (BLE) to a laptop running an analysis with the SciPy programming language, which displayed the results on a locally hosted webpage.

5 Iterations & Challenges

5.1 Task Distribution

Both authors contributed equally to this project, with each person participating in all aspects of the work. It is therefore difficult to distinguish individual contributions. Below is a list of the main tasks we collaboratively completed:

- **Physical Construction**
  - Sewing and cutting fabric materials

Figure 8: Heart rate sensor wrist band - *Whoop-Whoop*

Figure 9: Overview ZenBelt

Figure 10: Final prototype - What is inside

Figure 11: Final prototype

  - Iterative prototyping with various cloth pieces
  - Creating silicone pads (experimenting with different silicone types, pouring methods, and curing times)
- **Electronics Development**
  - Wiring and soldering components (e.g., solder own voltage divider circuit for the stretch sensors to ensure durability)
  - Testing and integration of hardware components
  - Creating reusable MicroPython libraries/APIs for every component (especially audio, vibration and air pumps)
- **Component Testing and Implementation**
  - Audio feedback system
  - Vibration feedback mechanism
  - Pneumatic system (air pumps and complete system)
- **Pneumatic System Development**
  - Physical setup (testing tube length, pad connection methods)
  - Electrical implementation (H-bridge configuration)
  - Software control (determining optimal inflation/deflation times)
  - System integration and testing

5.2 Creating Inflatables

Finding suitable inflatables was challenging. We experimented with various materials, including silicone, balloons, and plastic bags, ultimately developing consistent silicone pads after multiple iterations. The most consistent result was achieved with the *Rubber 1:1 R PRO 30*. The workflow can be delineated as such. Initially, the 3D-printed mold half, extending up to the marker, is filled. Subsequently, the mold is left to harden for approximately three hours. After this, it is recommended that a plastic cutout be performed, as illustrated in Figure 6. This should be followed by the application of a mold release spray. Subsequently, a second layer of silicone, as thin as possible, is to be applied into the mold.

5.3 Measuring Breathing

The calibration of the stretch sensor to differentiate between inhalation and exhalation for different users necessitated meticulous placement and coding to ensure precise measurements. This proved to be a challenge, especially in cases where users were not accustomed to breathing into the belly.

5.4 Integration

The integration of the stretch sensor, pneumatic components, a vibration sensor, a heart rate sensor, and an audio element necessitated meticulous temporal coordination to ensure a seamless user experience. Calibration and synchronization of measurements were imperative for the provision of real-time feedback.

5.5 Audio quality

Unfortunately, the quality of the speaker used in combination with the *DFPlayer mini* proved to be quite suboptimal. Due to time limitations, further exploration of the topic was not possible. In future work, an alternative might be to use the speaker of a connected device such as a smartphone or laptop.

6 Final Prototype

6.1 Description

The final prototype *ZenBelt* consists of a large piece of stretchy fabric that is folded over once and sewn together to make room for the inside. A speaker is sewn into the center front to guide the user through the exercise. The belt can be easily put on with two buckles that are sewn to the main area with sturdy fabric strips so that the length and therefore the fit can be adjusted. In the lower part of the interior, the cables are routed and three vibration motors are sewn in. The sewn-in stretch sensor and the tubes for the pneumatics are located in the upper area. The ten silicone pads are evenly distributed horizontally. From the user's point of view, all cables and the main tube exit the belt through a small hole on the right-hand side. With a length of approximately 1.5 m, this cable and tubing allow a little freedom for movement. The micro controller as well as both air pumps and the power bank are located in a box next to it, visible in Figure 11.

6.2 User Experience & Exercise

Firstly the user has to put on the belt around the belly. After securing it via the buckles the exercise can start. In the current status the program has to be started from a laptop. Though integrating a sort of switch into the buckle would be the preferred way to start the program in the near future. The program right now is structured into four parts.

1. Introduction, 2. Tutorial & Calibration, 3. Exercise, 4. Closing

Introduction and Closing currently consist only of audio tracks guiding the user. The calibration first asks the user to deeply inhale and then exhale, giving the system the minimum and maximum values for a specific user. Because the values heavily depend on the way the belt is worn as well as the users themselves. The Exercise then guides the user through several rounds of box breathing, 4 seconds of inhaling, holding, exhaling and holding again [1]. Guidance is given through the audio track indication in plain English what to do and the air cushions gently pushing against the belly to indicate an exhaling phase as well as releasing the pressure to allow a user to fully inhale. This is supported by the vibration motors clearly marking the start of the new phase. The system monitors the exercise via the stretch sensor and detects whether the monitored respiration patterns match. If a user deviates the system pauses the exercise and gently guides the user to start again at the current position. A mechanism that can be finetuned and improved in future work.

6.3 Implementation in context of *Deformable Interfaces*

This prototype implements the topic of *deformable interfaces* in various ways. The deformation of the belt through respiration, measured by the stretch sensor, is one of the key input modalities, serving as the foundation for the current interaction. Additionally, the deformation of the silicone pads, induced by the air pumped into them, communicates with the user via the deformation. The product's design, incorporating a deformable belt that can be shared among multiple users, underscores its flexibility.

7 Future Work

In the context of future research, there are several aspects that should be explored. Initially, there is a necessity to evaluate which feedback modalities have the most significant impact and determine if all are necessary for effective guidance. Secondly, conducting formal studies on the effectiveness of the system and comparing various breathing techniques beyond box breathing is imperative. Third, the miniaturization of the prototype should be pursued, with particular attention to integrating the air pumps directly into the belt, as opposed to their current housing in a separate box. These enhancements are expected to enhance portability and user experience while providing evidence-based validation of the system's efficacy.

8 Conclusion

The Zen Belt prototype effectively illustrates the potential of deformable interfaces to augment guided breathing exercises. Our process demonstrated the challenges and opportunities inherent in the creation of wearable technology that responds to and guides bodily movements. The integration of stretch sensors and pneumatic feedback establishes a natural interaction loop, where the belt both measures breathing and provides physical guidance. This core concept of utilizing deformation for both input and output has proven efficacious in testing and shows potential for future research.

The Zen Belt prototype demonstrates a promising trajectory for wearable technology that operates in harmony with the body, as opposed to merely adhering to it, thereby embodying the fundamental principles of deformable interfaces, a concept thoroughly explored throughout this course.

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